Charge Fluctuation of Dust Grain and Its Impact on Dusty-Acoustic Wave Damping

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Abstract. We consider the influence of dust charge fluctuations on damping of the dust-ion-acoustic waves. It is assumed that all grains have equal masses but charges are not constant in time - they may fluctuate in time. The dust charges are not really independent of the variations in the plasma potentials. All modes will influence the charging mechanism, and feedback will lead to several new interesting and unexpected phenomena. The charging of the grains depends on local plasma characteristics. If the waves disturb these characteristic, then charging of the grains is affected and the grain charge is modified, with a resulting feedback on the wave mode. In the case considered here, when the temperature of electrons is much greater than the temperature of the ions and the temperature of electrons is not great enough for further ionization of the ions, we show that attenuation of the acoustic wave depends only on one phenomenological coefficient

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INTRODUCTION

Dusty plasma represent the most general form of space, laboratory and industrial plasmas. Dusty plasma are conglomerations of the ions, electrons and neutral particles. These large particles, to be called grains, have atomic numbers Z_d in the range of $10^4 - 10^6$ and their mass m_d can be equal to 10^6 of the proton mass or even much more. In the considered dusty plasmas, the size of grains is small compared with average distance between the grains. The ratio of charge to mass for a given component of plasma determines its dynamics. We note that for dusty plasmas, ratio of electrical charges of grains to their masses is usually much smaller than in the case of multispecies plasmas with negative ions and hence, here comes the first of the crucial differences between multispecies plasmas with negative ions and dusty plasmas. If it is assumed that all grains have equal masses and charges steady in time, therefore the dust-ion-acoustic and dust-acoustic dispersion relations are obtained on the basis of fluid [3], [4] or kinetic [5] models. For simplicity we have assumed, that all grains have equal masses and charges, but charges are not constant in time - they may fluctuate in time. The dust charges are not really independent of the variations in the plasma potentials. Here, even in the fluid theory, appear the crucial differences between the ordinary multispecies plasmas and the dusty plasmas. All modes will influence the charging mechanism, and feedback will lead to several new interesting and unexpected phenomena. The charging of the grains depends on local plasma characteristics. If the waves disturb these characteristic, then charging of the grains is affected and the grain charge is modified, with a resulting feedback on the wave mode.

FLUCTUATION OF DUST GRAINS IN DUSTY PLASMAS

We consider the parallel electrostatic modes in an unmagnetized plasma when the temperature of electrons T_e is much greater than the temperature of ions T_i: $T_e \gg T_i$. In such simplified situations, fluctuations in time of the number density of electrons δn_e can occur due to the grains of the dust loosing or picking up some electrons. As a result of fluctuating dust charges in dusty plasmas, many new problems can appear which are in partly treatment by Verheest [6]. We also assume that the mass of grains with fluctuating charges may be approximated by constant values. In this case the continuity equations for specimens of dusty plasmas can be written in the form:

$$\begin{aligned}
\partial n_d/\partial t + \partial(n_d u_d)/\partial x = 0,\\
\partial n_i/\partial t + \partial(n_i u_i)/\partial x = 0,\\
\partial n_{e/}\partial t + \partial(n_e u_e)/\partial x = S_e.
\end{aligned} \tag{2.1}$$

Due to the possible fluctuations of the dust charges we can express the conservation of charge in the dusty plasma by:

$$\frac{\partial}{\partial t}\left(-n_e e + n_d q_d + n_i e\right) + \frac{\partial}{\partial x}\left(-n_e e u_e + n_d q_d u_d + n_i e u_i\right) = 0, \tag{2.2}$$

where q_d is the charge of grain of dust. This can be rewritten with the help of the continuity equation (2.1 - 2.3) as:

$$n_d\left(\frac{\partial}{\partial t} + u_d\frac{\partial}{\partial x}\right) q_d = eS_e. \tag{2.3}$$

On the other hand, the charge of grain of dust fluctuation is given by:

$$\frac{dq_d}{dt} = \left(\frac{\partial}{\partial t} + u_d\frac{\partial}{\partial x}\right) q_d = I_i\left(n_{i,} q_d\right) + I_e\left(n_e, q_d\right), \tag{2.4}$$

where $I_i\left(n_i, q_d\right)$ and $I_e\left(n_e, q_d\right)$ are the ionic and electronic charging current, respectively. When we combine (2. 3) and (2.4), we get

$$eS_e = n_d I_e\left(n_e, q_d\right) + n_d I_i\left(n_{i,} q_d\right). \tag{2.5}$$

In equilibrium dusty plasma, the total charging current vanishes:

$$I_{i0} + I_{e0} = 0, \tag{2.6}$$

where I_{i0} and I_{e0} denotes the equilibrium charging current for ions and electrons, respectively. Therefore we can expand (2.5) as a function of n_e, q_d and n_d using (2.6) and hence in linear approximation for S_e vanishing at equilibrium, it is given by:

$$S_e = -\nu_e \delta n_e - \mu_e \delta q_d, \tag{2.7}$$

where ν_e, μ_e denotes charging fluctuation coefficients while δn_e and δq_d denotes fluctuation electron number density and fluctuation charges of grains from their equilibrium values respectively.

DUMPING OF DUST-ION-ACUSTIC WAVE

Now we add to the continuity equation 2.1 some dispersion relations for ideal dusty plasma, when the fluctuation of the charge of the dust grain is absent. To determine dispersion relation we used the linear response theory [7], [8].

In Fourier representation we have

$$q_\alpha(k,\omega)\delta n_\alpha = k^2\chi_\alpha(k,\omega)\phi(k,\omega) \tag{3.1}$$

where δn_α- number density fluctuation of the α components of dusty plasma, χ_α- susceptibility. Dispersion relation for the ideal dusty plasma is given by

$$\varepsilon(k,\omega) = \varepsilon_0\left(1+\sum_\alpha \chi_\alpha(k,\omega)\right). \tag{3.2}$$

Then, using Poisson equation with global charge neutrality after linearization and Fourier transform we received:

$$\delta q_d(k,\omega) = \frac{-\nu_e \frac{e}{n_{d0}}\left(i\omega + \frac{e}{n_{d0}}\mu_e\right)\delta n_e(k,\omega)}{\omega^2 + \left(\frac{e}{n_{d0}}\mu_e\right)^2} \tag{3.3}$$

n_{d0} denotes the equilibrium number density of the dust. Next for $\alpha = e$ we received dispersion relation for acoustic wave, which take into account fluctuation of the grain charge:

$$1+\sum_\alpha \chi_\alpha(k,\omega) = \frac{-\nu_e \frac{e}{n_{d0}}\left(i\omega + \frac{e}{n_{d0}}\mu_e\right)\chi_e(k,\omega)n_{d0}}{e\left(\omega^2 + \left(\frac{e}{n_{d0}}\mu_e\right)^2\right)} \tag{3.4}$$

If $\chi_e \approx \frac{1}{k^2\lambda_{De}^2}$; $\chi_i \approx \frac{\omega_{pi}^2}{\omega^2}$ and $\chi_d \approx \frac{\omega_{pd}^2}{\omega^2}$ where $\lambda_{D\alpha}$, ω_{pd}^2 Debye length and plasma frequency for αcomponent respectively. In our case the ν_e and $\frac{e}{n_{d0}}\mu_e$ are smaller than

$$\omega_0 = \sqrt{\frac{k^2\lambda_{De}^2\omega_{pi}^2}{1+k^2\lambda_{De}^2} + k^2\frac{k_B T_i}{m_i}} \tag{3.5}$$

and the dispersion relation for DIAW waves is given by

$$\omega = \omega_0 + i\frac{k^2\lambda_{De}^2\omega_{pi}^2}{2\omega_0^2\left(1+k^2\lambda_{De}^2\right)}\nu_e. \tag{3.6}$$

For $k \longrightarrow 0$, we have

$$\omega = \omega_0 + i\nu_e\frac{\lambda_{De}^2}{2\left(\lambda_{Di}^2+\lambda_{De}^2\right)} \approx k\lambda_{De}\omega_{pi} - \frac{i\nu_e}{2} \tag{3.7}$$

This equation describes the dumped dust-ion-acoustic waves including the charge fluctuation. In our approximation: $T_e >> T_i$, $\omega_0 >> \nu_e$and $\omega_0 >> \frac{e}{n_{d0}}\mu_e$ then the dumping of dust-ion-acoustic waves is dependent on the one phenomenological parameter ν_e.

CONCLUSIONS

The paper deals with a small dust charge fluctuations. In the case considered here , when the temperature of electrons is much greater than the temperature of the ions: $T_e >> T_i$ and T_e is not great enough for further ionization of the ions, we show that attenuation of the acoustic wave depends only on one phenomenological coefficient ν_e. The value of this coefficient depends mainly on the temperature of electrons.

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